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FUNCTIONAL PROPERTIES AND *IN VITRO* DIGESTIBILITY OF NATIVE AND ACID-THINNED STARCHES FROM THREE NEGLECTED PURPLE CORN VARIETIES FROM CÔTE D'IVOIRE

Mariame CISSE[1], Flavie A. AKAFFOU[1], Edwige E. AKOA[1], KASSI AAE Murielle and *Djary M. KOFFI[1]

[1]*Faculty of Biosciences, Laboratory of Biotechnology, Agriculture and Biological Resources Valorization. University Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire.*

*Corresponding author: djaryss@gmail.com

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Abstract: *The objective of this study was to promote three purple corn varieties grown in Côte d'Ivoire, namely Katiola Purple. This was achieved by subjecting the starches to thinning, a chemical modification that has been widely employed to enhance their properties. The functional properties and enzymatic digestibility of these modified starches were then compared with those of the native starches. The thinned starches exhibited enhanced clarity and dispersibility, as well as increased hydration capacity. At 90 °C temperature, the thinned starches solubility increased significantly, reaching 66.04 g/g, 59.22 g/g and 62.16 g/g. The TDP, TPR and TLP starches exhibited a solubility of 13.46, 19.35 and 17.61, respectively, while the native NDP, NPR and NLP starches demonstrated values of 13.46, 19.35 and 17.61, respectively. The thinned starches also showed better in vitro digestibility and gelation capacity. The lower gelation concentration (0.5%) renders these thinned starches suitable for the infant food industry. Thinning also resulted in starches with low swelling power and reduced syneresis due to the low amylose content of the thinned starches. The significant reduction in syneresis is a highly noteworthy feature for preserving frozen foods. The acid thinning process has been shown to enhance the functional properties of native starches from purple maize varieties. The findings of this study provide valuable insights into the selection of the most appropriate applications for these starches in the food and non-food industries.*

Keywords*: Purple corn; Zea mays; Starch; Acid-thinning; Enzymatic digestibility; Functional properties.*

1. Introduction

In addition to being a very important nutrient, starch is an abundant, renewable, non-toxic, biodegradable, and inexpensive resource [1]. It is a natural semi-crystalline polysaccharide that is of increasing interest to industry for numerous food and non-food applications [2]. Corn starch is used in the food industry as a thickening and gelling agent, stabilizer, binder or emulsifier, and water-binding agent. These benefits justify their widespread use in ready meals, sauces, soups, baby foods, bakery products, confectionery, and jams. They are also used as excipients and sweeteners in many pharmaceutical tablets and capsules [3]. However, in their natural state, starches do not react well to high temperatures, prolonged cooking, appertization, etc., and their high viscosity makes them difficult to process. In addition, high viscosity, rapid swelling, and the phenomenon of retrogradation make these starches unsuitable for the manufacture of certain products [4]. As a result, starch is rarely consumed in its original native form [5]. To overcome these disadvantages and to meet

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specific technological and nutritional requirements, modified starches are used. The treatments that native starches undergo are either enzymatic, physical, or chemical and these allow all the advantages of native starch to be retained [2]. Chemical modifications of starch are used to correct defects in native starches, and one of the most common is thinning. Thinning, also known as fluidization, is a chemical modification aimed at treating starch to induce a greater or lesser degree of hydrolysis of the polymers. Depending on the intensity of the treatment, the hot viscosity of the starch is reduced [6]. The effect of these treatments is to weaken the granular structure to the point where the grains are soluble in cold water for the most advanced treatments [7] and to improve resistance to retrogradation [8]. Fluidized or diluted starches behave as highly soluble polymers that can be used in high concentrations without inducing high viscosities. They are used as texturing agents in confectionery gums or as nutritive agents in liquid preparations [9]. Cereal starches are very important since they make up 55-75% of the daily intake of human food and are the main source of food for domestic animals. Among these starches, corn starch is a valuable ingredient in food production, accounting for more than 80% of the world starch market [10].

In Côte d'Ivoire, purple corn, commonly known as Katiola purple, has been reported to contain substantial amounts of phenolic compounds, especially anthocyanins, and a significant amount of starch (about 65%) [11]. Recently, studies on the functional properties and *in vitro* digestibility of native and acetylated starches from three cultivars of this purple corn were carried out by Cissé et al. [12]. However, no studies have yet been carried out on the thinned starches from these different corn varieties. Given the strong industrial demand for starches and the needs of the Ivorian population, it would be interesting to study other types of modification of these starches derived from Katiola purple corn. The present study aimed to extract starches from the three purple corn varieties, carry out acid dilution, and determine the properties of the modified starches to propose a range of modified starches to meet food and non-food needs.

2. Materials and methods

Materials

The biological material consisted of dried grains of the three purple corn cultivars grown in Katiola (Fig. 1) and the digestive juice of snails (*Achatina achatina*) purchased at the Gouro market in Adjamé (Abidjan, Côte d'Ivoire).

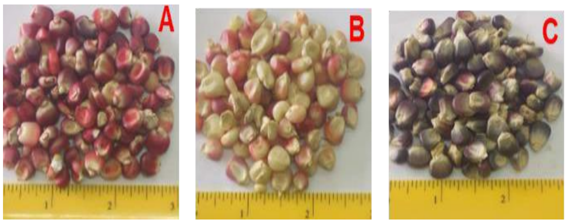

Fig. 1. Purple corn varieties produced in Côte d'Ivoire.
A: Purple red corn (PR); B: Light purple corn (LP); C: Dark purple corn (DP)

Methods

Starch isolation

Starches were extracted according to Delpeuch et al**.** [13] with some modifications. One kilogram of corn grains from each variety (PR, LP, and DP) was separately thoroughly washed with distilled water, soaked in a 0.1% sodium metabisulphite solution, and kept overnight in a refrigerator. The soaked grains were ground, and the obtained pastes were delayed in distilled water in the ratio 1/10 (W/V) with the addition of a sodium chloride solution (4%) to eliminate proteins by flocculation. The starches obtained in the separating funnel was then dried in an electric oven (Venticell, Fisher Bioblock Scientific, Germany) at 45 °C for 48 hours. The dried native starches were ground and sieved through a 250 µm sieve. These native starches were stored in hermetically sealed bottles and kept in a desiccator.

Preparation of the thinned starch samples

Acid-thinned starches were prepared according to the method of Wang et al. [14] with some modifications. A 40% paste concentration of each starch was prepared by dispersing each starch separately in 1 mol/L of aqueous hydrochloric acid. The reaction was carried out under automatic stirring for 3 hours at 50 °C in a water bath. The pH of the paste was then adjusted to 6.0-6.5 with 1 mol/L NaOH solution and then washed three times with distilled water before filtration. The starch samples were dried in an oven (Venticell, Germany) at 50 °C for 12 hours. The thinned and dried starch samples, namely the thinned dark purple (TDP), thinned red purple (TPR), and thinned light purple (TLP), were ground and passed through a 100 µm mesh sieve. The thinned starches were stored in hermetically sealed bottles and kept in a desiccator.

Functional properties

Craig et al [15] studied the clarity of starch gels by looking at light transmittance (%T). A high transmittance indicates greater clarity of the paste. Aqueous dispersions (1%) of starch were boiled at 100°C and stirred continuously for 30 minutes. The paste was dried at room temperature and stored at 4°C for 4 weeks. Transmittance was measured at 650 nm weekly using a spectrophotometer (Jenway 7315, England). The method described by Coffman and Garcia [16] was used to assess the least gelation concentration. Test tubes containing aqueous starch suspensions (1, 2, 4, 6, 8 and 10%; w/v) were manually shaken for 2 minutes at room temperature (28 ± 2°C) and then heated in a boiling water bath for 1 hour. The tubes were then rapidly cooled to 4°C in a refrigerator for 30 minutes. It was found that the least gelation concentration corresponds to the suspension with minimum gel concentration whose gel could not slip or fall out when the tube was inverted.

Syneresis was evaluated by the method of Singhal and Kulkarni [17]**.** A 5% (w/v) starch suspension was heated in a water bath at 100°C for 30 minutes with gentle agitation. The obtained paste was poured into centrifuge tubes at a rate of 10 grams per tube. Three tubes were conditioned at room temperature (28°C) and left to stand for 20 minutes before being centrifuged at 2,700 rpm for 30 minutes. The remaining tubes were stored in the refrigerator at 4°C for four weeks. Each week, three tubes were removed from the refrigerator and thawed at 28 ± 2°C for three hours. These tubes were then centrifuged under the conditions described above. Each test was performed in triplicate. The percentage of syneresis was then calculated as follows:

$$\boldsymbol{Syneresis}\ (\%) = \frac{\boldsymbol{m_w}}{\boldsymbol{m_g}} \times \mathbf{100}$$

$\mathbf{m_W}$: mass of water (g) separated from the gel after centrifugation.
$\mathbf{m_g}$: mass of gel (g) removed.

The swelling and solubility experiments were conducted using the modified technique described by Leach et al. [18]. In summary, a 1% (w/v) starch suspension was created and subjected to stirring in a water bath for 30 minutes. The temperatures of the water bath ranged from 50 to 90 °C, with intervals of 10 °C. Next, the samples underwent centrifugation at a speed of 4500 rpm for a duration of 20 minutes. The

pellets and supernatants were collected in separate flasks for the dry matter determination at 105 °C for 24 hours. Experiments were carried out in triplicate for each sample.
Swelling (G) was determined according to the following equation:

$$\boldsymbol{G}\ (\boldsymbol{g}/\boldsymbol{g}) = \frac{\boldsymbol{m_{w-}m_d}}{\boldsymbol{m}}$$

$\boldsymbol{m_W}$: wet mass (g) of aliquot.
ms: dry mass (g) of aliquot.
m: mass (g) of the sample.

The amount of solubilized starch was calculated using the following formula

$$\boldsymbol{S}\ (\%) = \frac{\boldsymbol{E}}{\boldsymbol{m}} \times \mathbf{100}$$

E: mass (g) of dried supernatant
m: mass (g) of sample

The cold hydration and oil absorption capacities of native and thinned starch samples were determined by the method described by Phillips et al [19]. The dispersibility (D) of the starch samples was estimated by the method described by Iromidaya et al [20].

Enzymatic digestibility
An aliquot (100 mL) of starch suspension (2%; w/v) was mixed with 80 mL sodium acetate buffer (100 mM pH 5.0) and 20 mL of the diluted (1/400) enzyme extract. Several tubes were prepared and incubated in a water bath at 37°C for different times (0.5, 1, 2, 4, 8, 20 and 24 h). The reducing sugars obtained by enzymatic hydrolysis were determined according to the method of Bernfeld [21].

Statistical analysis

All experiments were performed in triplicate and results were expressed as mean and standard deviation. One-way analysis of variance (ANOVA) was performed using STATISTICA 7.1 to determine any statistical (significant) differences between the calculated means. Duncan's test, at a confidence level of 95%, was used to highlight the statistical differences.

3. Results and discussion

Paste Clarity
A clear starch paste is defined as one that gives a sharp, intense image of an object viewed through it. The percentage transmittance (%T) (percentage of light transmitted through the sample) is used to measure clarity using a spectrophotometer [15]. As concerned our stache samples, during the first two weeks of storage, a rapid decrease in the clarity of the paste obtained with the native starch isolated from the three corn varieties and their respective acid-treated samples was observed. However, the clarity tended to stabilize during the remaining 2 weeks. The clarity of the paste prepared from the starch samples is a function of the type of corn from which they have been isolated (Fig. 2).The brightness of native starch pastes (NDP, NPR and NLP) and thinned starches (TDP, TPR and TLP) of purple corn was initially low, with values of 0.7±0.2, 0.9±0.1, 1.1±0.1, 1.8, ±0.1 2.6±0.3 and 4.4±0.1% T, respectively. Among the three varieties, native and thinned starches from light purple corn (NLP and TLP) which is less rich in anthocyanin (the pigment responsible for the purple colour), had the best transmittance at 1.1±0.1 and 4.4±0.1%T, followed by those of purple red (PR). Moreover, all the thinned starches had higher transmittance percentages than the native starches. The acid action improves the initial transmittance by 61.11% for DP, 65.38% for PR, and 75% for LP. The

storage of native starch pastes as thinned in the refrigerator at 4°C resulted in a decrease in transmittance for all varieties. This decrease was 42.85%, 66.66% and 63.63% for the native starch paste NDP, NPR and NLP respectively, whereas it was 47.22%, 63.46% and 56.81% for the thinned starches (TDP, TRP and TLP). At the end of four weeks, the transmittance of NDP and NLP was 0.4% and that of NPR was 0.3%. With the thinned starches, the transmittance was 0.85% for TDP and 0.95% for TLP and TPR. A decrease in light transmission with storage time was also reported in the literature by Tetchi et al**.** [22], Cisse et al. [23], and Ashogbon et al. [24]. This decrease in the paste transparency during cold storage (4°C) could be due to a significant reorientation of the solubilized starch chains [25]. Thinned starches exhibited much higher transmittance than native starches throughout the storage period. At the end of the storage period, an improvement in clarity of more than 50% was observed in the thinned starches. This increase in paste clarity after thinning agrees with the results reported for normal corn starch by Liu et al. [26]. This could be attributed to a better stability of the starch structure due to thinning which allowed improved inter- and intra-molecular bonding [27]. In addition, acid-thinned starch gels contain short, low-molecular-weight chains that allow improved light transmittance. This behaviour could prove essential in foods such as fruit jellies and compotes [27] .

The least gelation concentration and dispersibility

The lowest gelling concentration is the value at which gelling begins. It is of great importance in culinary preparations [28]. A low value indicates high thickening power. The native starches have values of 2% for NDP and NPR and 1% for NLP. (Table 1). With thinning, these lowest concentrations dropped to 0.5% for all the treated starch samples (TDP, TPR, and TLP).

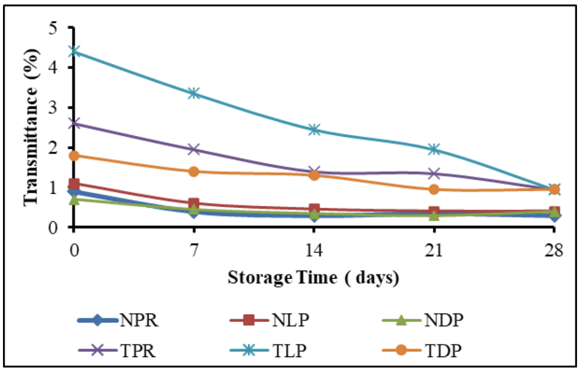

Fig. 2. Evolution of the transmittance of native and thinned starch pastes stored at 4 °C
NDP : Native Dark Purple ; NPR : Native Purple Red ; NLP : Native Light Purple ; TDP : Thinned Dark Purple ; TPR : Thinned Red Purple ; TLP : Thinned Light Purple

This reduction varies from 75% for TDP and TPR to 50% for TLP. Similar results have been reported regarding the improved gelling capacity of corn, potato, and rice starches after acid thinning [29]. The lowest values observed for the thinned starches revealed a significant improvement in gelling capacities. Gelatinization is an important starch property in the food industry, as most starches are consumed gelatinized [30].

Dispersibility refers to the ability of particles to disperse easily in liquids. It plays an essential role in many characteristics of finished products such as colour, sensory quality, film uniformity, therapeutic efficacy, shelf life and UV protection in cosmetics [31]. The dispersibility of the native starches increased with acid thinning (Table 2). All the native starches (NDP, NPR, and NLP) showed a similar dispersibility (64.7%). However, as starches were treated with acid, this dispersing capacity varied, with higher values observed for TDP and TPR (72.54%) than for TLP (70.58%).

Compared to their respective native starches, all the thinned starches showed better dispersibility and the net increases in dispersibility were 10.79% for both TDP and TPR and 8.31% for TPL. Therefore, it could be inferred that higher dispersibility will be obtained with TDP and TPR than with TPL. Moreover, the higher the dispersibility is the better the reconstitution properties [32]. Also, higher dispersibility improves foaming and emulsifying properties, which would be suitable to produce bread, macaroni, and biscuits [33]. In addition, high dispersibility would facilitate wetting and spreading of the aqueous starch paste, which would have a positive effect on adhesion [34].

Table 1.
Dispersibility and least gelation concentration of native and thinned starches of three varieties of purple corn produced in Côte d'Ivoire.

Type of starch	Dispersibility (%)	Least gelation concentration (%)
NDP	64.71±1.1^{c}	2±0.0^{a}
NPR	64.71±1.3^{c}	2±0.0^{a}
NLP	64.71±1.4^{c}	1±0.0^{b}
TDP	72.54±1.2^{a}	0.5±0.0^{c}
TPR	72.54±1.1^{a}	0.5±0.0^{c}
TLP	70.58±1.2^{b}	0.5±0.0^{c}

NDP : Native Dark Purple ; NPR : Native Purple Red ; NLP : Native Light Purple ; TDP : Thinned Dark Purple ; TPR : Thinned Red Purple ; TLP : Thinned Light Purple . Values given are the averages of at least three experiments ±SE. Values followed by different superscript on the same column are significantly different (P=0.05).

Syneresis

The syneresis is the amount of water released from the starch paste after cooling and cold storage. This phenomenon is highly undesirable in the food industry [35]. The water presence on the product would make it less attractive, which would have a major impact on its acceptability.
Syneresis results are shown in Fig. 3. Syneresis increased with time during storage. Results showed that maximum syneresis was observed in native starches. For the acid-thinned starches, no syneresis was observed after 7 days for TPR and TLP, and 14 days for TDP. At the end of the storage period (fourth week), the highest retrogradation was observed for NDP (52.47%), followed by NPR (47.48%) and NLP (46.2%) and the net increases in syneresis were 40.29% for NLP, 38.14 for NDP and 31.92% for NPR. For the acid-treated starches, the maximum syneresis was observed for TDP (33.13%), followed by TPR (25.2%) and TLP (19.62%), in agreement with the results reported by Takizawa et al. [36]. This low syneresis could be explained by a lower amylose content. Wang and Wang [29] stated that the high degree of cleavage of the glycosidic bonds of long amylopectin chains by the action of acids is responsible for the decrease in the starch paste viscosity.

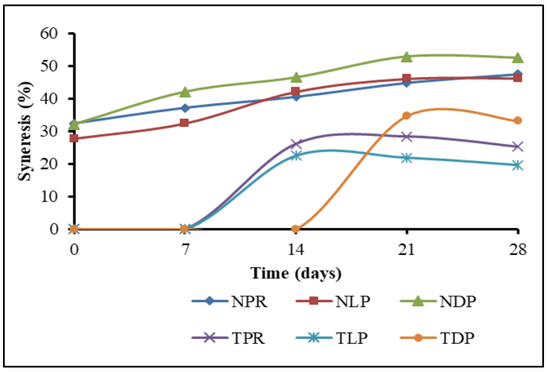

Fig. 3. Evolution of the syneresis of native and thinned starches of three purple corn varieties at stored at 4°C NDP: Native Dark Purple; NPR: Native Purple Red; NLP: Native Light Purple; TDP: Thinned Dark Purple; TPR: Thinned Red Purple; TLP: Thinned Light Purple

Generally, starch retrogradation is influenced by its conformational structure, which in turn influences the degree of granule disruption during gelatinization as well as the interactions that occur between starch chains during gel storage [37]. The lack of syneresis observed for the acid-thinned starches after at least a week of storage could be useful in frozen food production. Indeed, starch stability is essential for the stability of frozen foods [5].

Swelling and solubility

The swelling power is an indicator of water absorption by starch granules during hydrothermal processing. The functional use of starch in food processing can be predicted by the starch swelling process. Swelling has an impact on the texture, flavour, digestibility, and nutritional properties of starch-based foods [38].
Fig. 4 shows that the water absorption of native and thinned starch is affected differently by the temperature applied. The swelling power of native starches (NDP, NPR, and NLP) was less affected by temperatures below 60 °C and increased steadily with the increasing temperature. At 90 °C, NDP had a swelling power of 12.60 g/g while NPR and NLP had a swelling power of 13.19 and 13.24 g/g respectively. Statistically, there is no difference between the three varieties in terms of starch swelling. Gelatinisation begins at 70°C, with the starch grains absorbing water and swelling irreversibly. Increasing temperature increased the swelling capacity of the starches by decreasing their intragranular bonding strengths, which allowed more water to enter the crystalline component of the starches [39]. As regards the acid-thinned starches (TDP, TPR, and TLP), three different phases in the capacity of the starch to absorb water and swell during heating were observed. From 50 to 60°C, the swelling power was not affected by the range of temperatures applied. In this range, the starch has not reached gelatinisation temperature. The grains have had very little water absorption. From 60 to 80°C, an increase in the swelling power value was observed. At 80°C, TLP showed a higher increase in swelling power (10.98 g/g) than TDP (9.91 g/g) and TPR (8.70 g/g). The net increases in swelling power were 73.33% for TDP, 70% for TPR and 75.68% for TPL. From 80 to 90°C, a decrease in the swelling power of the starch grains was observed. However, at 90°C, TLP still has the highest swelling power (8.25 g/g) followed by TDP (7.83 g/g) and TPR (6.95 g/g). The net decreases in swelling power were 21% for TDP, 20.11% for TPR and 24.86% for TPL. Of all the studied starches, TLP had the highest swelling value. This could be explained by its low amylose content. According to Lei et al [40] a high amylose content reduces starch swelling.
Between 60 and 70°C, a steady increase in swelling power was noticed for all starch types, in agreement with the results reported by Sasaki and Matsuki [41]**.** However, at higher temperatures (80-90°C) the swelling power of the acid-treated starch was negatively affected. A similar result was observed in the work of Sandhu et al. [42] on normal and waxy corn. During the acid treatment of the starch, the hydronium ion (H_3O^+) attacks the glycosidic oxygen atoms and hydrolyses the glycosidic bonds. It preferentially degrades the amorphous region because the crystalline zone is not easily accessible to the acid, thus leaving it virtually intact and consequently increasing the relative crystallinity. This increased crystallinity is responsible for the reduced swelling capacity of the acid-thinned starches since swelling is limited by the rigidity of the amylopectin networks entangled in the crystalline region of the starch [43].
Aqueous solubility is the maximum mass of solutes after hydrothermal action. The irreversible swelling of starch granules leads to the solubilisation and leaching of amylose in water. higher values of solubility were observed for NLP (17.72%) and NPR (18.82%) and lower values for NDP (13.46%). After acid treatment, the solubility of the thinned starches ranged from 3 to 4.9 at 50 °C and increased with

the gradual increase in temperature. Between 70 and 80 °C the solubility of TDP was lower than the others, but at 90 °C its solubility was higher (66.04%) than that of TLP (62.16%) and TPR (59.22%). At 50 °C, the solubility of the native starches varied between 1 and 2.58 and increased with temperature. At 90 °C,

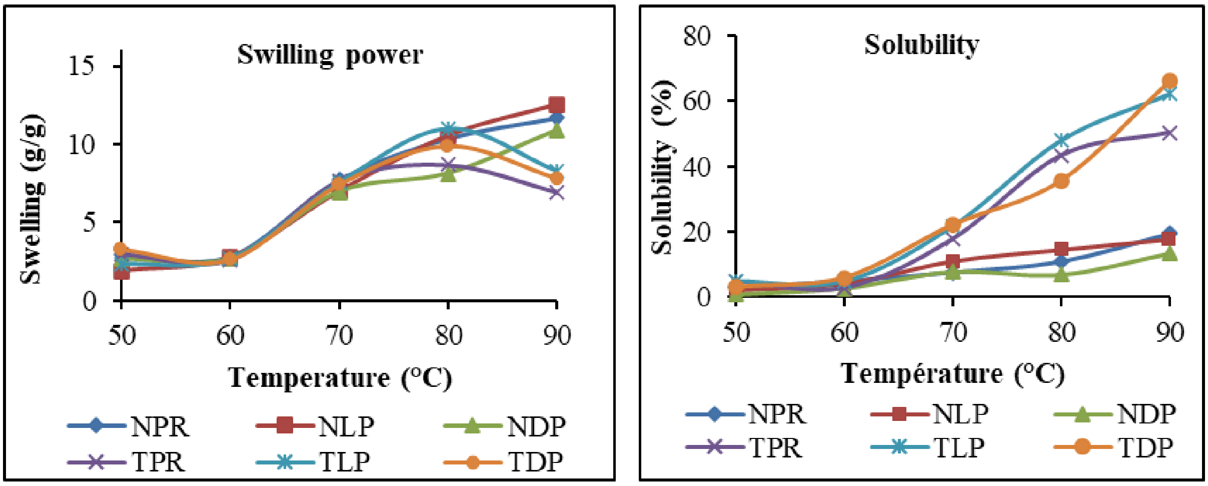

Fig. 4. Swelling power and solubility of starches from the three purple corn varieties at stored 4 °C
NDP: Native Dark Purple; NPR: Native Purple Red; NLP: Native Light Purple; TDP: Thinned Dark Purple; TPR: Thinned Red Purple; TLP: Thinned Light Purple

Acid treatment of the starch leads to greater dissociation of inter and intra-hydrogen bonds, causing the dissociation of the amylose and linear branches of amylopectin in suspension. The depolymerization and structural weakening of the starch granule, leading to the leaching of the the starch granule amorphous region, is responsible for the increase in solubility observed after acid thinning. The results obtained in this study agree those of Jyothi et al. [44] on cassava starch. Sandhu et al. [42] also reported a decrease in swelling power and an increase in solubility upon acid hydrolysis of normal and waxy corn starches. Moreover, the solubility values obtained in our study (59.22 - 66.04%) are higher than those previously found by Sandhu (36.9 - 50.5%) on thinned starches of wazy corn [42].

Water Hydration Capacity

The water hydration and oil absorption capacities define the avidity of the starch for water or oil. It plays an important role in the starch ability to form a paste, which is a decisive characteristic for the choice of application in the food industry.

The water hydration capacity of starches is presented in Table 2 and varies according to the origin of the starch. As the concentration (w/v) of the samples increases, the water hydration capacity decreases.

Table 2.
Water Hydration Capacity of native and thinned starches of three purple corn varieties according to starch concentration

Starch Concen-trations	Water Hydration Capacity (%)					
	NDP	NPR	NLP	TDP	TPR	TLP
2%	255.99±11.84^{aA}	253.59±9.88^{aA}	249.30±3.09^{bA}	278.87±7.92^{aA}	256.25±26.86^{aA}	266.33±0.47^{aA}
4%	231.71±13.5^{bB}	229.34±4.73^{bB}	226.37±9.15^{bB}	253.47±1.4^{aB}	242.73±13.75^{aAB}	241.42±0.06^{aB}
6%	223.35±0.45^{bC}	225.05±1.82^{bB}	212.53±7.02^{cC}	235.19±2.63^{aC}	235.86±0.93^{aB}	239.14±2.33^{aB}
8%	223.42±6.03^{bC}	203.70±2.42^{cC}	208.60±1.94^{cC}	236.21±1.48^{aC}	226.81±1.33^{bC}	229.07±0.45^{bBC}
10%	212.04±2.61^{cD}	205.57±1.13^{dC}	204.35±0.30^{dCD}	223.24±3.06^{aD}	218.61±1.91^{bCD}	215.97±1.74^{bD}

NDP: Native Dark Purple; NPR: Native Purple Red; NLP: Native Light Purple; TDP: Thinned Dark Purple; TPR: Thinned Red Purple; TLP: Thinned Light Purple
Values on the same line with different lower-case letters are significantly different according to Duncan's multiple comparison test. Values in the same column with different uppercase letters are significantly different.

The decrease rates from 2% to 10% were 17.66%, 18.93 and 17.97% for NDP, NPR and NLP respectively and 19.94, 14.68 and 18.90% for TDP, TPR and TLP. These results contrast with those of Tanoh et al [45] in their studies on starches from different cassava varieties of Côte d'Ivoire. For all concentrations, native starches (NDP, NPR, and NLP) showed lower values than thinned starches (TDP, TPR, and TLP), and for all samples, the highest hydration capacity was observed with 2% starch concentration.
At 2% concentration, the hydration capacity of native starches varied from 249.30 ± 3.09% (NLP) to 255.99 ± 11.84% (NDP) while those of acid-thinned starches were 278.87 ± 7.92 % for TDP, 266.33 ± 0.47% for TLP, and 256.25 ± 26.86% for TPR. The three thinned starches show no significant difference. Compared to their respective native starch, net increases of 8.94%, 6.39%, and 1.05% were observed. These differences observed in water absorption capacity could be attributed to the size and integrity of the granules. According to Lucas-Gonzàles et al. [46] the water absorption capacity evolves in inverse correlation with the size of the flour granules. Acid-thinned starches have a significantly higher hydration capacity than native starches. This suggests that thinned starches are likely to have more hydrophilic groups than native starches. In addition, the weakening of association strengths between starch polymers in modified granules may be responsible for the increase in hydration capacity [47, 48]. The action of the acid would expose more of the starch hydroxyl groups by reducing the high molecular weight of the native chains to low molecular weight dextrin's, thus increasing the binding sites availability for water. All starches, preferably thinned starches, could be used in product formulations that require hydration to improve texture [46].

Oil absorption capacity

The ability of starch to absorb oil is a measure of its emulsifying potentials. The oil absorption capacity is also important as it improves the mouth feel and retains flavour [20].
The oil absorption capacity of the starches is shown in Table 3. As the concentration

(w/v) of the samples increases, the oil absorption capacity decreases. These decrease rates from 2% to 10% starch concentrations were of 55.47%, 46.97 and 35.80% for NDP, NPR and NLP respectively and 36.61%, 20% and 27.74% for TDP, TPR and TLP.

At 2% starch concentration, the oil absorption capacity varied from 90.15±6.86b% (NLP) to 191.76±4.66% (NDP) while the acid-thinned starches showed values of 105.38±12.99% for TDP, 84.90±6.10% for TLP, and 90.00±11.45% for TPR. Compared to their respective native starches (NDP, NLP and NPR), net decreases of 45.04%, 5.82% and 24.54% in oil uptake values were observed. A similar result was obtained by Zhang et al. [49] for studies carried out on native and sonicated maize starch grown in Sanghai.

Native starches could be used in fried products to help prevent them from feeling too greasy, and in foods requiring good emulsifying properties [46]). The capacity to absorb oil decreases due to the reduction in the number of binding sites available in the amorphous region of the starch granule [50].

Enzymatic hydrolysis

The enzymatic digestibility is the ability of a substance to be digested by enzymes into a smaller fraction. It is influenced by several factors such as amylose/amylopectin ratio, granular structure, helical structure, gelatinisation and retrogradation degrees [51].

Table 3.
Oil absorption capacity of native and thinned starches of three purple corn varieties according to starch concentration.

Starch Concen-trations	Oil absorption capacity (%)					
	NDP	NPR	NLP	TDP	TPR	TLP
2%	191.76±4.66^{aA}	139.66±7.08^{bA}	90.15±6.86^{cB}	105.38±12.99^{cA}	90.00±11.45^{cBC}	84.90±6.10^{cB}
4%	122.64±3.87^{bB}	117.37±2.87^{cB}	113.34±4.24^{cA}	101.48±5.56^{cA}	133.65±8.70^{aA}	126.28±3.04^{bA}
6%	97.70±3.26^{aC}	86.59±0.11^{bC}	78.20±3.58^{bC}	72.02±0.23^{dC}	83.50±1.40^{bC}	80.79±3.28^{bB}
8%	90.53±1.43^{aD}	85.41±0.18^{bC}	66.50±0.00^{dD}	82.19±1.26^{bB}	82.04±1.83^{bC}	77.57±4.07^{cBC}
10%	85.39±0.70^{aE}	74.05±1.97^{bD}	57.84±14.7^{cdD}	66.80±1.22^{cD}	72.52±4.07^{bD}	61.35±0.85^{dD}

NDP: Native Dark Purple; NPR: Native Purple Red; NLP: Native Light Purple; TDP: Thinned Dark Purple; TPR: Thinned Red Purple; TLP: Thinned Light Purple
Values on the same line with different lower-case letters are significantly different according to Duncan's multiple comparison test. Values in the same column with different uppercase letters are significantly different.

Enzymatic digestion is an important non-toxic process that promotes the cleavage of starch chains into lower molecular weight products such as maltodextrin, dextrin, and glucose, which are widely used in food industries.

Fig. 5 shows the enzymatic hydrolysis of native starches and their thinned derivatives. In general, a biphasic digestion pattern was observed during the hydrolysis of all starches by the amylolytic enzymes of snail *Achatina achatina*. An initial phase of strong increase between 0 h and 4 h for both native and thinned starches, with values ranging from 0 to 0.62 mg/mL and 0 to 0.80 mg/mL respectively. The second phase, from 5 h to 20 h, was one of moderate growth, with the level of reducing sugars increasing slowly until it reached 1.01 for the native starches, which showed no difference between them throughout the digestibility curve, whereas for the thinned starches, although the trend of the curves was the same, they showed a slightly better digestibility with values of 1.064 for TPR, 1.218 for TLP and 1.04 for TDP.

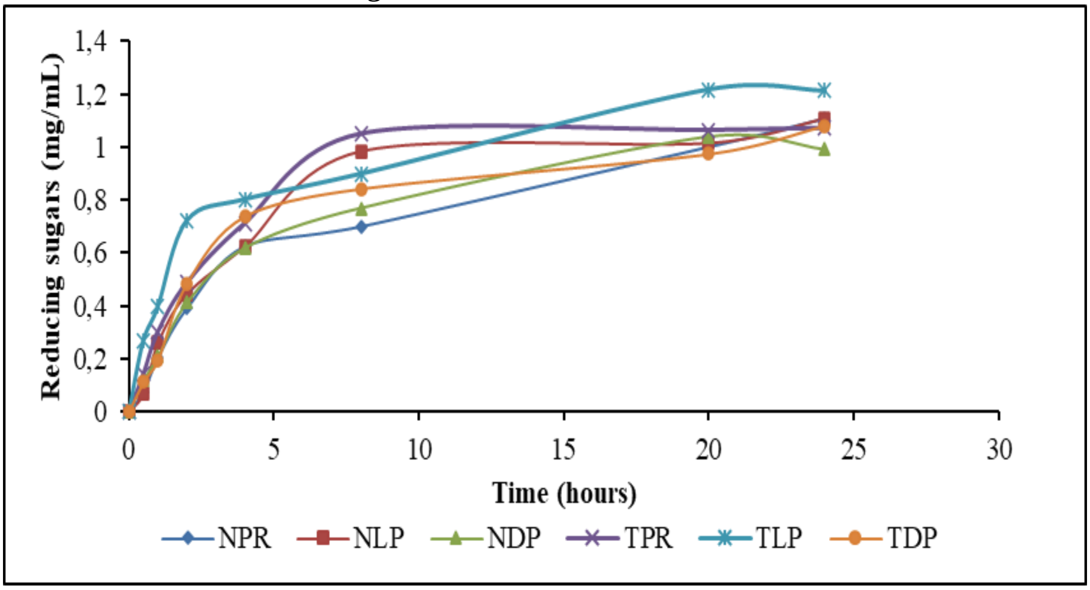

Fig. 5. *In vitro* enzymatic hydrolysis of native and thinned starches from three purple corn varieties NDP: Native Dark Purple; NPR: Native Purple Red; NLP: Native Light Purple; TDP: Thinned Dark Purple; TPR: Thinned Red Purple; TLP: Thinned Light Purple

This slight increase could be explained by the weakening of the starch granules after modification. This weakening is due to the increased hydrophilic character of the modified starches. The different hydrolysis phases could be explained by the rapid hydrolysis of the starch amorphous part, the second, much slower phase corresponding to the crystalline part hydrolysis [52]. These observations are consistent with an increase in the digestibility of corn starch after hydrolysis [26].

4. Conclusion

To sum up this report, it appears that all the thinned starches showed improved clarity, solubility, dispersibility and gelling power. After thinning, the starches showed low swelling power at 90°C and low syneresis after storage at 4°C.

Regarding the three thinned starches, TLP showed the highest clarity, the best swelling and solubility rates and no syneresis after one week of storage. The oil absorption capacity decreased while the water absorption capacity increased. The thinned starches were more digestible than their native counterparts. We conclude that acid thinning improved the studied functional properties of native starches of purple corn varieties. The property profile of these thinned starches could be of interest for the preparation of fruit compotes, pasta, bread, and cookies.

5. References

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